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MICHTOX: A Mass Balance and Bioaccumulation Model for Toxic Chemicals in Lake Michigan

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Notice

The information in this document has been obtained primarily through funding by the United States Environmental Protection Agency (USEPA) under the auspices of the Great Lakes National Program Office (GLNPO) and the Office of Research and Development (ORD). The report has been subjected to the Agency's peer and administrative review and it has been approved for publication as a USEPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Because the purpose of this report is to document the development of the MICHTOX model, conclusions are historical and should not be considered current.

Foreword

Federal and contractor staff at the United States Environmental Protection Agency's Large Lakes Research Station have been involved with the development of mass balance models for the Great Lakes since the early 1970s. MICHTOX is a mass balance model developed to predict chemical concentrations in water and sediments of Lake Michigan in response to chemical loads to the lake. The model was adapted from the general water quality model WASP4. The MICHTOX bioaccumulation model was based upon the WASTOXv4 food chain model. Development of MICHTOX began in the early 1990s. The model was developed as a planning tool for the Lake Michigan Mass Balance Project (LMMBP) (U.S. Environmental Protection Agency, 1997). This work was documented in an in-house report in 1992 (Part 1). The model was applied as a screening-level model for atrazine in Lake Michigan in support of the LMMBP (Rygwelski *et al*., 1999). The model was slightly revised and applied to polychlorinated biphenyls (PCBs) in Lake Michigan to confirm model results with the LMMBP project data and to provide preliminary modeling results for inclusion in the 2002 Lake-wide Management Plan (LaMP) report (Lake Michigan Technical Committee, 2002). These were reported in a 2002 contractor report (Part 2). The purpose of this report is to document through 2002 the progression of MICHTOX model development and application of the model to describing the behavior of contaminants, especially PCBs, in Lake Michigan. Both parts of this report have been cited numerous times in the literature. This report provides ready access to these for interested parties. For PCBs, results from application of the model have been superceded by more recent results.

Lake Michigan Technical Committee. 2002. Lake Michigan Lakewide Management Plan (LaMP), 2002. U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Illinois. 102 pp.

Rygwelski, K.R., W.L. Richardson, and D.D. Endicott. 1999. A Screening-Level Model Evaluation of Atrazine in the Lake Michigan Basin. J. Great Lakes Res., 25(1):94-106.

U.S. Environmental Protection Agency. 1997. Lake Michigan Mass Budget/Mass Balance Work Plan. U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Illinois. EPA/905/R-97/018, 155 pp.

Abstract

MICHTOX is a toxic chemical mass balance and bioaccumulation model for Lake Michigan. It was developed for the United States Environmental Protection Agency's Region V in support of the Lake Michigan Lake-wide Management Plan (LaMP) to provide guidance on expected water quality improvements in response to critical pollutant loading reductions. The 11 critical pollutants modeled were benzo(a)pyrene, chlordane, total dichlorodiphenyltrichloroethane (DDT), dieldrin, heptachlor epoxide, hexachlorobenzene, lead, total polychlorinated biphenyls (PCBs), 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), 2,3,7,8-tetrachlorodibenzofuran (TCDF), and toxaphene. Concentrations of these were predicted in 17 water and sediment segments in response to atmospheric and tributary loadings. The bioaccumulation model was coupled to the mass balance model to predict chemical accumulation in lake trout and bloater through pelagic and benthic food chains. Mass balance predictions were validated using plutonium, lead, and PCBs data; and bioaccumulation predictions were validated with PCBs data. The model was later applied to provide preliminary PCBs model results for the Lake Michigan Mass Balance Project. Results from this application were used to guide the development of a more resolute model for PCBs. Results for PCBs described in Part 1 are superceded by results in Part 2. Part 2 results have been replaced by a more recent application of MICHTOX that has been presented at various meetings and will be published at a future date. This document is meant to provide a historical perspective of MICHTOX development and application.

Table of Contents

List of Figures

List of Tables

Abbreviations

AOCs	Areas of Concern
BAF	Bioaccumulation factor
BaP	Benzo(a)pyrene
BCF	Bioconcentration factor
BMC	Bayesian Monte Carlo
BSF	Biota-to-sediment factor
BSR	Biota-to-sediment ratio
CV	Coefficient of variance
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
EPRI	Electric Power Research Institute
ERL	Environmental Research Laboratory
GBMBP	Green Bay Mass Balance Project
GLEC	Great Lakes Environmental Center
GLNPO	Great Lakes National Program Office
HCB	Hexachlorobenzene
HOCs	Hydrophobic organic chemicals
LaMP	Lake-wide Management Plan
LCL	Lower confidence limit
LMMBP	Lake Michigan Mass Balance Project
LLRFRB	Large Lakes and Rivers Forecasting Research Branch
LLRS	Large Lakes Research Station
lnCV	Lognormal coefficient of variance
MDNR	Michigan Department of Natural Resources
MED	Mid-Continent Ecology Division
NSOM	Non-settling organic matter
PCBs	Polychlorinated biphenyls
PCB4	Tetrachlorobiphenyl
PCB5	Pentachlorobiphenyl
PCDD	Pentachlorodibenzo-p-dioxin
PCDF	Pentachlorodibenzofuran
QAPP	Quality Assurance Project Plan
TCDD	Tetrachlorodibenzo-p-dioxin
TCDF	Tetrachlorodibenzofuran
UCL	Upper confidence limit
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VWA	Volume-weighted average

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Executive Summary

MICHTOX is a toxic chemical mass balance and food chain bioaccumulation model that was first developed in the early 1990s. A Bayesian Monte Carlo uncertainty analysis demonstrated that MICHTOX predicted polychlorinated biphenyl (PCBs) concentrations should be within a factor of two of the measured data. During the early part of the Lake Michigan Mass Balance Project (LMMBP), MICHTOX was updated and used as a preliminary assessment tool of the LMMBP PCBs data and to provide a screening-level analysis of the potential future trends in total PCBs concentrations in Lake Michigan water, sediment, and fish under a variety of contaminant load scenarios.

As reported in 1992, the model predicted the response of Lake Michigan, and with additional resolution, Green Bay to atmospheric and tributary loadings. With its bioaccumulation component, chemical accumulation in biota was predicted in response to the loadings. The model is capable of either dynamic or steady-state simulations. Dynamic model predictions were used to predict the long-term rate of concentration decline following load reduction for each toxic chemical. Significant reductions of PCBs in lake trout were predicted for 2000 with no additional loading reductions. Additional reductions of PCBs concentrations could only be achieved with significant reductions in atmospheric sources. These results were uncertain because PCBs loading history is poorly defined and because of potential error in the parameterization of the surficial sediment layer thickness. The thickness of this layer was demonstrated to be a critical factor in model uncertainty. Additional factors leading to model uncertainty included uncertainty in initial concentrations and loading history and dynamics of the Lake Michigan trophic structure.

As reported in 2002, MICHTOX was used to provide a preliminary mass balance modeling assessment of PCBs in Lake Michigan. Because PCBs vapor concentrations from the LMMBP were significantly higher than estimated in the original model, total PCBs forcing functions were recalculated using the LMMBP estimates. Recommended changes to the model increased the volatilization mass transport rates, resulting in the PCBs equilibrium shifting significantly towards the atmospheric vapor phase quicker than previously predicted. This demonstrated that air-water fluxes predominated the transport pathways for PCBs in Lake Michigan. The best prediction of PCBs concentrations in water, sediment, and fish were obtained with the forcing function peaking in 1961-1963. This was different than the original model simulation reported in 1992. The model was used to forecast total PCBs concentrations in lake trout for a variety of scenarios representing alternative strategies for managing PCBs in Lake Michigan. Because of model uncertainty, observed average total PCBs concentrations should be within a factor of two of predicted values. The bioaccumulation predictions were not sensitive to initial conditions but were sensitive to model parameterization. The PCB predictions of this model are historic and have been replaced by the predictions derived from the improved models used for the LMMBP.